

THE RELATIONSHIP BETWEEN GEOMETRIC DESIGN CONSISTENCY AND SAFETY ON RURAL SINGLE CARRIAGEWAYS IN IRELAND

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1. ABSTRACT

Rural single carriageways in Ireland tend to fall below current design standards and have higher accidents rates (per vehicle kilometre) than roads designed to modern standards. Resources are not available to improve all rural single carriageways; therefore sections need to be identified as priority sections for improvement. Geometric design consistency studies can be used to identify inconsistent sections on highways, which can then be targeted for improvement. No geometric data exists for rural single carriageways in Ireland. A method of estimating geometric data from digital maps was implemented on some 70km of highways. 19 curves and 19 tangents were then selected to represent the overall geometric makeup of the highway. Numerous geometric indices were measured on site. A spot speed survey was conducted at the midpoint of each tangent and curve and operating speed was calculated for each site. The spot speed survey is used to estimate the operating speed on straights (tangents). An operating speed model is used to estimate the operating speed on curves. Using these estimated operating speeds a sample geometric design consistency evaluation is carried out. Elements were classified as good, fair or poor using a design evaluation criterion. An accident database for the N52 was obtained. Accidents that occurred on the N52 and were possibly caused by the road alignment were extracted from the database. 53 accidents at 40 locations were observed. 19 of these accidents occurred in locations that were classified good, 8 accidents occurred in locations classified fair and 13 accidents occurred in locations classified as poor. A relationship exists between geometric design consistency and safety. Of the 40 locations which had accidents over the 8 year period from 1999 – 2005, 13 of these locations were detected as needing re-alignment by the geometric design consistency evaluation. A geometric design evaluation can be used to pin point locations on highways where accidents could conceivably be higher. Improvement works and resources can therefore be concentrated on these sections and hence rural single carriageways can be made safer.

2. INTRODUCTION

Road fatalities are a significant problem in Ireland. The number of road related fatalities to date in 2007 has reached 221 (as of 28th August 2007, Garda National Traffic Bureau). Although this is a reduction in fatalities in comparison the same period in 2006, it still represents a large number of fatalities. The

Road accidents are complex events involving a variety of factors, including highway geometry, driver behaviour, weather conditions, speed limits and human factors. This paper focuses specifically on highway geometry, its effect on the speed of vehicles and its effect on safety. Single carriageways make up 89.8% of the principal road network in Ireland, the 'national roads', (NRA, 2006). The fatal collision rate of an average rural single carriageway national road is approximately twice that of a dual carriageway road with at-grade junctions and approximately six times that of a motorway (EuroRAP, 2005). The majority of these rural single carriageways are un-designed roads. These routes were developed in the past and follow no specific engineering design code. Resources available for these roads are limited as the majority of funding is earmarked for improving roads with higher traffic volumes.

Geometric design consistency evaluations are a widely used method of determining sections of highways which require alignment improvement. This method identifies geometric inconsistencies on highways by means of design evaluation criteria. Following such assessments the allocation of funding to reduce the geometric inconsistencies can be prioritised.

To conduct a geometric design consistency evaluation a great deal of information is required. Alignment data for a substantial section of road is necessary, as is a method of determining the operating speed on roads. This type of information is not readily available in Ireland. The paper will describe the methods used to gather this information and the subsequent geometric design consistency evaluation. This evaluation in conjunction with accident data will be used to establish whether there is a link between geometric design consistency and safety.

3. BACKGROUND

Generally, geometric design consistency measures are divided into four distinct categories. Operating speed, vehicle stability, driver workload and alignment indices.

Operating speed is defined as the speed selected by highway users when not restricted by other users (Poe et al. 1996), and is normally represented by the 85th percentile operating speed. In terms of geometric design consistency, operating speed (V_{85}) is widely considered to be the most notable and straightforward geometric design consistency measure. The change in speed of vehicles is a visible indicator of inconsistency in geometric design (Nicholson, 1998). Several interpretations of operating speed as a geometric design consistency measure have been made in the literature. The operating speed can be used in consistency evaluation by examining the variation between the design speed (V_D) and V_{85} on a particular section of highway or examining the differences between V_{85} on consecutive highway elements (ΔV_{85}). Safety criteria I & II (Table 1.1) show the most common set of criteria used to determine the level of consistency of a highway section in relation to operating speed (Lamm, 1988). Table 1 classifies highway sections into three categories. Where, Good = no highway alignment corrections are required; Fair = no alignment correction is required, but corrections may be desirable to signs, camber etc.; and Poor = alignment redesign is recommended.

DESIGN EVALUATION	CRITERION I	CRITERION II	CRITERION III
GOOD	$ V_{85} - V_D \leq 10 \text{ km/hr}$	$\Delta V_{85} \leq 10 \text{ km/hr}$	$\Delta f_R = f_R - f_{RD} \leq 10.0$
FAIR	$10 < V_{85} - V_D \leq 20 \text{ km/hr}$	$10 < \Delta V_{85} \leq 20 \text{ km/hr}$	$0.01 > \Delta f_R \geq -0.04$
POOR	$ V_{85} - V_D \geq 20 \text{ km/hr}$	$\Delta V_{85} \geq 20 \text{ km/hr}$	$\Delta f_R < -0.04$

Table 1.1, Design Evaluation Criteria

These are the most well known set of safety criteria. However, they may suffer from several shortcomings (Hassan, 2004). The safety criteria were developed from accident studies in New York and caution should be employed when implementing these models in other locations (Lamm, 1988). Criterion I, for example, would suggest there is no difference between a value of 10.1 km/hr for $|V_{85} - V_D|$ and a value of 20.0 km/hr for $|V_{85} - V_D|$. They both lie in the same category - "Fair". But values of 19.9 km/hr and 20.1 km/hr for $|V_{85} - V_D|$ lie in two different categories, "Fair" and "Poor" respectively. This creates a step form of the two criteria and is a concern (Hassan, 2004). The same step form of criteria exists for Criteria II.

Criterion III is based on vehicle stability on horizontal curves. Vehicle stability is paramount in ensuring road safety. A vehicle negotiating a horizontal curve experiences excessive centripetal forces, vehicle rollover and head-on collisions can be attributed to these forces (Hassan et al., 2001). Locations that do not provide vehicle stability can be considered geometric design inconsistencies. Safety Criterion III in Table 1.1 was suggested to evaluate design consistency through ensuring that enough side friction supply (f_R) is available to meet the side friction demand (f_{RD}) as the vehicles negotiate a horizontal curve. Side friction supply, often referred to as side friction assumed, on any given horizontal curve is calculated using the following formula (Lamm, 1991):

$$f_R = 0.25 - (2.04 \times 10^{-3} V_D) + (0.63 \times 10^{-5} V_D^2) \quad (3.1)$$

This formula assumes a flat topography. A point mass formula is used to calculate f_{RD} (AASHTO, 2001):

$$f_{RD} = (V_{85}^2 / 127R) - e \quad (3.2)$$

where R = curve radius (m); V_{85} = operating speed on element (km/hr); and e = super-elevation rate. Criterion III examines the difference between f_R and f_{RD} (Δf_R) on a particular section of highway. This criterion suffers from the same shortcoming as safety criteria I and II in that it creates a step form of criteria. The formulae were developed in the United States so again caution should be employed when implementing them in other countries. Both formulae are subject to substantial criticism in the literature. The friction values used to develop (3.1) are based on research that was carried out in the thirties and forties (Hassan, 2004). Measurement techniques have come a long way since then; they also would not take into account modern vehicle and tyre design. Equation 3.2 treats the entire vehicle as a point mass. It does

not take into account the interaction between the vehicle tyres and the pavement, which is the principal method of keeping a vehicle on the highway. Side friction is not easy to recognise and measure as operating speed (Hassan et al., 2001).

Driver workload is defined as the time rate at which drivers must perform a given amount of driving tasks that increases with the increase of the complexity of highway geometric features (Messer, 1980). The mental workload of drivers due to inconsistencies may not be as readily observable as previous measures, it may however, lead to more collisions (Nicholson, 1998). Highway designers should avoid highway sections with a very high or very low driver workload. Driver workload seems to represent an appealing method of evaluating design consistency. It measures the actual mental workload on the driver, i.e. the difficulty level that a driver experiences while safely negotiating a section of highway. Changes in this workload could conceivably lead to errors.

Methods for estimating driver workload are documented in Wooldridge et al., (2000a, b) and in Messer, (1980). However, the use of driver workload as a measure of consistency is much more limited than operating speed (Gibreel et al., 1999). Both methods have their shortcomings and it should be noted that a relationship between driver workload and safety performance is yet to be documented (Hassan, 2004).

Alignment indices are quantitative measures of the general character of a highway segment's alignment (Anderson et. al, 1999). They are not subject to any evaluation criteria however it is noted that geometric inconsistencies will occur when the general character of an alignment changes significantly (Hassan et. al, 2001). Examples of alignment indices in the literature include average radius of a section (AR), ratio of maximum radius to minimum radius on a section of highway (RR) and the ratio of the radius of a single horizontal element to the average radius of the entire section (CRR).

4. ESTIMATION OF HIGHWAY GEOMETRY

After taking several considerations into account the N52 was selected as the road for the study (Figure 4.1; Google, 2007)



Figure 4.1, Map of N52

The arrows in the above map indicate the start and points of the section of N52 used in this research.

Reasons for selecting the N52 for this research included: digital mapping for this road was readily available and of good quality, the road had a reasonably high traffic volume and it was within a close proximity to Dublin. The N52 is a 'national secondary road'. These roads are secondary to the main arterial routes – the national primary roads.

The horizontal alignment of the N52 had to be estimated. This was done using digital maps. Digital maps offer an economic and time saving data source which can be used to extract horizontal alignment characteristics (Hashim and Bird, 2004). This study details a simple method to practically estimate the highway geometry. Other methods to estimate highway geometry exist including extracting highway geometry from laser scanning and aerial photographs (Hatger and Brenner, 2003) and estimating highway alignment through geographic information system (GIS) applications (Lupton et al., 1999). These methods are relevant, but for the purposes of this study it was decided that the method described in Hashim and Bird, 2004 would be used. This method was easier to implement and would produce results quicker.

Digital maps for seventy kilometres of the N52 were obtained from Ordnance Survey Ireland in AutoCAD format. These maps were digitized from paper maps; they were not based on a survey, hence their accuracy is not guaranteed. As the maps were digitised from paper maps they contained

ancillary information that was not needed for this study. The road edge lines and centreline were isolated from the rest of the map. The centreline in the maps is designed to fall between the edge lines of the road but this definition is done graphically on the map and it is not surveyed or verified on site.

The start and end points of the curves (critical points) needed to be located. Once the critical points are located the geometric characteristics of the road can be estimated (curve radius, curve length, tangent length etc.). To locate the critical points, the road was to be divided into 5 metre sections (Hashim and Bird, 2004). Straight lines were drawn perpendicular to the edge line at 5 metre intervals using AutoCAD. The TRIM command in AutoCAD was used to fit the perpendicular lines between the edge lines. The midpoint of each perpendicular line was located and joined, creating a new centreline (Figure 4.1).

The midpoints of the lines were extracted. The length of each segment of the centreline was calculated using the Cartesian coordinates (x, y) of the midpoints. The bearing of each segment was also calculated from the following formula:

$$\text{Bearing} = (y_i - y_{i+1}) / (x_i - x_{i+1}) \quad (4.1)$$

The bearing is calculated for consecutive sections. The bearing trend is used to determine the critical points. If *at least four* consecutive bearing trends are of the same tendency, i.e. consecutive bearing trends are positive, negative or zero, those elements can be considered a curve or a tangent (Table 4.1).

	<i>Bearing Trend</i>	<i>Consecutive Bearing Trends Indicate</i>
$Bearing_1 = Bearing_2$	0	Tangent
$Bearing_1 > Bearing_2$	Positive	Left Turn Horizontal Curve
$Bearing_1 < Bearing_2$	Negative	Right Turn Horizontal Curve

Table 4.1, Definition of bearing trend

Fluctuations of bearing between positive, negative and 0 indicate a tangent. When at least four consecutive bearings are found to be equal, the point where the bearing trend changes is defined as the end point of the element (curve or tangent) and the start point of the next element (Figure 4.1).

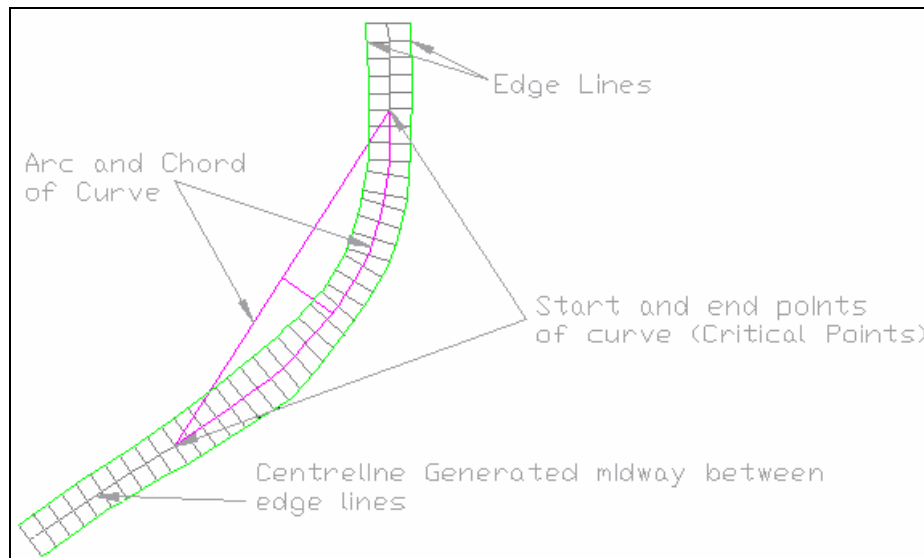


Figure 4.1, Alignment estimation

Once the critical points were known the alignment characteristics (length of element, the radius of the curve (R) and the deflection angle) were easily calculated using basic geometry. This method was validated against a section of road with known geometry and found to be reliable (Hashim and Bird, 2004).

Only rural roads were considered in this research. Sections of the road that went through towns were excluded. A summary of the data that was extracted when the above method was implemented on the N52 between Tyrellspass and Ardee is presented in Table 4.2.

Type of Element (#)	Measurements (m)	Min	Max	Mean	Standard Deviation
Curve (560)	Curve Length (L_c)	18.594	320.959	37.792	33.501
	Curve Radius (R)	48.362	997.351	352.256	237.948
	Deflection Angle (DA)	1.149	111.846	10.811	13.832
Tangent (499)	Tangent Length (L_t)	9.258	1122.043	106.682	131.933

Table 4.2, Summary of characteristics of road

Every curve with a radius over 1000m was treated as a tangent (Hashim and Bird, 2004). The above table represents the alignment data for 74.436 km of rural single carriageway. The deflection angle (DA) of a curve was calculated from the following equation (Hashim and Bird, 2004):

$$DA = (\text{Curve Length} / R) * (180 / \pi) \quad (4.2)$$

More curves were found in this study than were found in other similar studies. 560 curves and 499 tangents were found in this study, which is more than twice the amount found in previous research on a similar amount of road (Hashim and Bird, 2004).

<i>Mean Measurements (m)</i>	<i>Watters and O'Mahony (2007)</i>	<i>Hashim and Bird (2004)</i>
Curve Length (L_c)	37.792	94.896
Curve Radius (R)	352.256	347.019
Deflection Angle (DA)	10.811	21.634
Tangent Length (L_t)	106.682	238.144

Table 4.3, Comparison of characteristics of road

Table 4.3 compares the characteristics of the road survey in this study and the road surveyed in Hashim and Bird (2004). Values for mean R are similar. The mean L_c differs greatly indicating that shorter curves were found in this study. The shorter curves found are also reflected in the lower value for DA. Tangent lengths are also much shorter. Of the 499 tangents detected, only 57 were found to be independent tangents (greater than 200m).

5. OPERATING SPEED

Operating speed (V_{85}) data was collected in order to formulate an operating speed model. This research was only concerned with cars. Data was collected by means of a spot speed survey.

Sites for the spot speed survey were selected to cover the different highway characteristics on this type of road (e.g. different curve radius, length deflection angle and tangent length). Previous research has suggested that 50 spot speed observations at each site in each direction would be adequate to estimate the operating speed at each location (Hashim and Bird, 2005). Speed data was only collected in daylight hours on a dry pavement. All the selected sites had a speed limit of 100km/hr and were not near any junctions or towns. Irish Grid coordinates of the midpoint of each curve and tangent were obtained from the digital maps. A handheld global positioning system was used to pinpoint the location of each curve or tangent.

Traffic counters were used to measure the speeds of cars on curves. Traffic counters were laid at the midpoint of 19 curves and were left in position for a minimum of 2 hours. This allowed sufficient time to collect a minimum of 50 spot speeds in each direction. The data was downloaded from the traffic counters onto a PDA and in turn transferred to a computer for analysis.

A computer program, MetroCount Traffic Executive, was used to screen the data. The traffic counters categorise vehicles by recording the number of axles and the time taken for those axles to travel over the traffic counter. The ARX classification scheme was used to classify the vehicles in MetroCount. This scheme defines cars as having 2 axles and a wheelbase of between 1.7m and 3.2m. As this research is only concerned with cars, all vehicles that did not meet this classification scheme were excluded from the database. The data were collected for all types of vehicles in the traffic stream under free-flow conditions. Lamm et al. (1990) considered free flow conditions to be isolated vehicles with a time gap of at least 6 seconds. Poe et al. (1996) assumed that the case of free-flow conditions would occur when the headways are equal to or greater than 5 seconds. Accordingly, in this study it

was considered that the data representing the free-flow conditions are those of isolated vehicles with a minimum headway of at least 5 seconds. Vehicles heading a platoon were also considered to be experiencing free flow conditions. All cars with a headway of less than 5 seconds were removed from the database, the remaining observations were considered to be cars in free flow conditions. A summary of the results of the speed survey on curves is shown in Table 5.1.

	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Operating Speed (V_{85}) (km/hr)	75.7	16.7	48.2	104.8
Mean Speed (km/hr)	61.2	10.1	43.0	87.1
# Spot Speeds per site	151	94	107	386
Curve Radius (R) (m)	235.223	148.055	48.362	514.892
Curve Length (L_c) (m)	120.386	91.102	18.895	320.959
Deflection Angle (DA) (deg.)	43.863	34.636	3.481	111.846
Paved Width (W_p) (m)	6.9	0.9	6.0	10.1
Width between edge lines (WI) (m)	6.4	0.8	5.7	9.0

Table 5.1, Summary of speed survey on curves

Speeds on the tangents were collected using a Speedar Radar Gun by Ottery Electronics. The radar gun allowed the recording of the maximum speed reached by cars on the tangents. Traffic counters would only collect the speed of a car at a certain point on the tangent. Laser guns can follow the car and record the maximum speed reached. A minimum of 50 spot speed observations were taken at 19 sites deemed to be tangents. Again, only cars in free flow conditions were recorded i.e. cars with at least 5 seconds of headway.

If drivers perceive that speed enforcement is present, such as a radar gun, they tend to slow down (Misaghi and Hassan, 2005). To minimise the effect of perception of speed enforcement, spot speeds were taken from inside a vehicle which was positioned adjacent to each tangent, thus obscuring the traffic's view of the radar gun. The positioning of the vehicle did not affect traffic flow or the speed of vehicles travelling on the road. A summary of the results of the speed survey on tangents is shown in Table 5.2.

	<i>Mean</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>
Operating Speed (V_{85}) (kph)	97.0	6.8	81.3	105.6
Mean Speed (kph)	86.5	6.0	73.5	95.4
# Spot Speeds per site	101	1	100	104
Tangent Length (L_t) (m)	294.778	197.452	34.886	919.882
Paved Width (W_p) (m)	7.5	1.5	5.9	12.0
Width between edge lines (W_l) (m)	6.4	0.8	5.2	7.5

Table 5.2, Summary of speed survey on tangents

The values presented in this paper produced similar results to other spot speed survey conducted on two lane rural carriageway curves in Europe. A sample comparing the results presented in this paper (Watters and O'Mahony, 2007a) to other European studies is shown in Table 5.3.

	Watters and O'Mahony (2007)			Dell'Acqua et al. (2007)			Hashim and Bird (2005)			Kanellaidis et al. (1990)	
<i>Location</i>	Ireland			Italy			UK			Greece	
<i>Road</i>	N52			SP312, SP30b, SP52			-			-	
<i>Value</i>	<i>Mean</i>	<i>Min</i>	<i>Max</i>	<i>Mean</i>	<i>Min</i>	<i>Max</i>	<i>Mean</i>	<i>Min</i>	<i>Max</i>	<i>Min</i>	<i>Max</i>
<i>Operating Speed (km/hr)</i>	75.7	48.2	104.8	84.0	76	98	87.4	67.6	105.9	51	116
<i>Curve Radius (m)</i>	235.2	48.4	514.9	587.9	25	5000	410.4	108.1	931.6	50	1100
<i>Curve Length (m)</i>	120.4	18.9	321	89.6	33	256	196.4	39.7	795.5	-	-
<i>Deflection Angle (deg.)</i>	43.9	3.5	111.8	31.7	1.7	118.5	31.3	7.2	78.4	-	-
<i>Paved Width (m)</i>	6.9	6	10.1				8	6	9.6	-	-
<i>Distance Between Edgelines (m)</i>	6.4	5.7	9	6.4	5	10	7.5	6	9.4	-	-
<i>Lane Width (m)</i>	-	-	-	-	-	-	-	-	-	3.5	3.8
<i>Shoulder Width (m)</i>	-	-	-	-	-	-	-	-	-	0	2.5

Table 5.3, Spot Speed Surveys on Curves in Europe

Only a sample of studies that have been conducted in Europe over the past 20 years is shown in Table 5.3. These studies have all investigated the operating speed on rural two lane carriageways. Extensive research has also been conducted in the United States and Canada. The table represents spot speed surveys that were carried out on rural road curves. Both radar guns and traffic counters were used to collect the data and only data for cars in free flow conditions was documented. The speed limit on the roads in Hashim and Bird, 2005 was 100km/hr, while the speed limit was not mentioned in the other two comparative studies.

Dell'Acqua et al. (2007) and Kanellaidis et al. (1990) included curves with a radius of over 1000 in their spot speed surveys. These were not included in Hashim and Bird (2005) or in this study. This study produced the lowest value

for mean operating speed. However, this is to be expected as it also has the lowest value for mean curve radius and the highest value for mean deflection angle. Similar road widths were observed in Italy and Ireland, while larger road widths were observed in the UK and Greece.

Few studies in Europe have examined operating speed on tangents. Hashim and Bird, 2005 found the mean operating speed on tangents to be 95 km/hr compared to 97 km/hr found in this study.

6. SAMPLE GEOMETRIC DESIGN CONSISTENCY STUDY

An operating speed model for curves on rural two lane carriageways was formulated from the data observed in the spot speed survey and various geometric variables. This model is presented in Watters and O'Mahony (2007b).

It was also intended to formulate an operating speed model for tangents on rural two lane carriageways. However, one could not be formulated from the data. This has happened in previous studies; operating speed on tangents is more difficult to model than operating speed on curves (Fitzpatrick et al., 2005). To estimate the operating speed on non - independent tangents (tangents less than 200m) the speeds on the adjacent curves were used. These speeds were predicted by the curve operating speed model (Watters and O'Mahony, 2007b). The spot speed survey results were used to estimate the operating speed on independent tangents. The length of each independent tangent was examined, the spot speed survey results were consulted and the operating of the tangent with an equivalent length was chosen to be the operating speed of that particular independent tangent.

Once the operating speeds of all elements were known a geometric design consistency evaluation was conducted using Safety Criterion II of Table 1.1. This is an operating speed based safety criterion; which is widely regarded as the most appropriate method of identifying design inconsistencies. The shortcomings of the vehicle stability and driver workload based measures are of more concern than those of the operating speed based measures (Hassan, 2004). As mentioned previously the criteria described in Table 1.1 are the most common criteria used in geometric design consistency evaluation. The safety criteria suffer from shortcomings but they are the easiest and quickest ways to establish if design inconsistencies exist on highways. Criterion II was chosen as the design speed for the N52 was not known. Only the operating speeds for the individual design elements were known.

The operating speed on each element was compared to the operating speed on the preceding element for both directions of travel on the N52. The absolute value of the difference between the operating speeds was calculated, the criterion was consulted and a design evaluation classification of good, fair or poor was applied to every element.

7. ACCIDENT ANALYSIS

The accident database for the N52 was obtained from the NRA; accidents from 1999 to 2005 inclusive were examined. The data base contained 533 accidents of varying degree. However, not all of these accidents occurred on the N52. Accidents that did not occur on the N52 were excluded. Only accidents that could have been caused by the alignment of the road were needed for analysis. These accidents were extracted in line with previous research (Anderson et al., 1999). Only non-intersection accidents that involved the following were considered: (a) a single vehicle running off the road, (b) a multiple-vehicle collision between vehicles travelling in opposite directions, or (c) a multiple-vehicle collision between vehicles travelling in the same direction. All accidents involving parking, turning, or passing manoeuvres; animals in the roadway; pedestrians and bicycles or motorcycles were excluded.

The Irish grid coordinates for the accidents were obtained from the accident reports. Using AutoDesk Civil 3D 2008, the accidents were plotted onto the digital maps mentioned earlier in this paper digital maps using. The text of the accident report was used in conjunction with the digital maps to allocate accidents to the correct elements (e.g. curve or tangent). The accident report usually indicates if the accident occurred on a curve or not. Once plotted any accidents that were not on the N52 were excluded.

53 accidents remained after the exclusions. These accidents occurred on 40 elements during the 8 year period.

The accident locations were compared to the geometric design consistency evaluation. It was found that 19 of these accidents occurred in locations that were classified good, 8 accidents occurred in locations classified fair and 13 accidents occurred in locations classified poor.

8. CONCLUSIONS

- The method used to estimate the highway geometry detected more curves and tangents on the road surveyed in this study than a similar length of road surveyed in the UK. This suggests that rural two lane carriageways undulate more in Ireland than in the in the UK.
- The mean operating speed on curves in Ireland is lower than that of roads in other European countries. This is to be expected as the survey conducted in this study was done on much tighter curves.
- A relationship exists between geometric design consistency and safety. Of the 40 locations that had accidents over the 8 year period from 1999 – 2005, 13 of these locations were detected as needing re-alignment by the geometric design consistency evaluation.
- Geometric design evaluations can be used to pin point locations on highways where accidents could conceivably be higher. Improvement

works and resources can therefore be concentrated on these sections and hence rural single carriageways can be made safer.

9. REFERENCES

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